glass completely replaced by fine-grained smectite and

(or) zeolites, of which clinoptilolite is the most common

and flow breccia, as much as 225 m thick, of dark-gray,

densely porphyritic, hypersthene basaltic andesite on Lit-

tle Kalama-Lewis River divide in northeastern part of

quadrangle. Typical flow contains phenocrysts of plagio-

clase (about 35 percent; 1 to 2 mm long), hypersthene (6-

8 percent; 1 to 3 mm long), and augite (<0.5 percent; 1 to

2 mm across) in intergranular to intersertal groundmass of

feldspar, pyroxene, Fe-Ti oxide, and local interstitial

quartz and smectite. Upper several meters commonly

olithologic diamicton composed of angular clasts as large

as 1 m of dark-gray to reddish-gray, aphanitic to seriate,

sparsely vesicular basaltic andesite in yellowish-gray ma-

trix of comminuted basaltic andesite. Predominantly clast-

supported but lower part of unit shows inverse grading

and higher proportion of matrix. At least 50 m thick. Base

not exposed; top locally weathered to limonite-stained and

bleached saprolite. In adjacent Deer Island quadrangle,

unconformably overlain by micaceous sand and gravel of

Troutdale Formation (Ttf). Clasts consist of plagioclase,

augite, and altered olivine crystals ≤1 mm across in an in-

tergranular to trachytic groundmass of plagioclase, clino-

pyroxene, and Fe-Ti oxides; groundmass crystals locally

enclosed by scattered equant oikocrysts (≤0.5 mm) of hy-

persthene. Texture of deposit similar to 1980 debris-ava-

lanche deposit at Mount St. Helens. Wilkinson and others

(1946) interpreted the breccia as a lens within the Trout-

dale Formation and inferred it was the product of contemporaneous volcanism. Petrographic similarity to some Eo-

cene basaltic andesite flows and an 40Ar/39Ar age of

land quadrangle (Evarts, 2002) suggests it is actually an

Eocene unit, although an origin as a Neogene landslide

Little Kalama River valley of distinctive, medium- to

dark-gray, orange-weathering, porphyritic to seriate basalt

containing abundant conspicuous, red to orange, variably

altered olivine as the only or most abundant phenocryst

phase. Olivine phenocrysts (about 10 percent; 1 to 3 mm

across) are partly replaced by smectite + hematite \pm cal-

cite and contain abundant minute octahedral chromite in-

clusions. Flows also contain phenocrysts or microphenoc-

rysts of plagioclase (≤5 percent; ≤1 mm long) and augite

(\leq 5 percent; \leq 1 mm across); the augite occurs as multi-

grain clots of anhedral crystals. Medium-grained trachytic

groundmass composed of plagioclase, augite, Fe-Ti oxide,

and minor interstitial glass altered to smectite. Smectite

and zeolites fill irregular microvesicles. May be correla-

tive with similar rocks (basaltic andesite of Indian George

Creek) mapped by Evarts and Ashley, (1991) in Lakeview

Contact—Dashed where approximately located; short-dashed

Fault—Dashed where inferred; dotted where concealed. Ball

Axis of anticline—Approximately located; showing direction

Strike and dip of compaction foliation in pumiceous lapilli

Strike and dip of platy parting in lava flows

Sample locality for chemical analysis—See table 1

Approximate area of propylitic alteration

and bar on downthrown side. Arrows show relative hori-

Peak quadrangle to the northeast

zontal movement

Strike and dip of beds

Horizontal

Vertical

Horizontal

where inferred; dotted where concealed

Olivine-phyric basalt (Eocene)—Two or more flows in lower

deposit cannot be ruled out

37.3±0.3 Ma from sample collected in adjacent Deer Is-

Basaltic andesite breccia (Eocene)—Massive, unsorted, mon-

weathered to reddish-orange saprolite

Hypersthene basaltic andesite (Eocene)—Sequence of flows

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Thickness of surficial units exaggerated

Geologic Map of the Woodland Quadrangle, Clark and Cowlitz Counties, Washington Russell C. Evarts

Glacial deposits

Outwash deposits of Amboy Drift (Pleistocene)—Unconsolidated, sand and pebble and cobble gravel; moderately weathered, crudely stratified, and moderately sorted to well-sorted. Forms scattered dissected terrace remnants with treads generally below 200 ft (60 m) elevation on both sides of Lewis River valley. Composed largely of well-rounded clasts, some grooved or striated, of diverse volcanic rocks similar to Tertiary rocks of the Cascade Range; lack quartzite and Columbia River Basalt Group clasts, indicating a Lewis River rather than Columbia River source. Locally contain clasts similar to middle Pleistocene olivine-phyric basalts and basaltic andesites erupted from monogenetic vents in the Lewis drainage upstream from quadrangle (Evarts and Ashley, 1990a, 1991). Clasts of distinctive, coarsely porphyritic, quartz-, biotite-, and cummingtonite-bearing dacite of the type erupted from the ancestral volcanic center of Mount St. Helens (Crandell, 1987) locally are a minor but conspicuous component in the gravels. Weathering rinds on aphanitic andesitic clasts from upper part of weathering profiles are generally 1-2 mm thick. Interpreted as glaciofluvial deposits of the Amboy Drift (Mundorff, 1984). Based on weathering characteristics, Amboy Drift is correlative with Hayden Creek Drift, which Crandell and Miller (1974) interpreted to be the product of the penultimate glaciation in the Washington Cascade Range. Age of the Amboy/Hayden Creek Drift uncertain; estimates range from about 50 ka to greater than 300 ka (Crandell and Miller, 1974; Crandell, 1987; Colman and Pierce, 1981; Dethier, 1988; Grigg and Whitlock, 2002; Evarts and others, 2003)

Outwash deposits of Drift of Mason Creek (Pleistocene)— Semiconsolidated gravel and sand; deeply weathered, commonly limonite cemented, and moderately to well sorted. Composed of well-rounded cobbles and pebbles of volcanic rocks similar to those exposed in the adjacent the Cascade Range, indicating a Lewis River source. Deposits contain no clasts attributable to Mount St. Helens volcano, but locally include a few basalt or basaltic andesite clasts possibly derived from small, middle Pleistocene, monogenetic volcanic centers in the Lewis River drainage upstream from quadrangle (Evarts and Ashley, 1990a, 1991). Weathering rinds on aphanitic andesite clasts range in thickness from 2 to 15 mm and average about 6 mm. Unit forms dissected terraces with surfaces at about 400 ft (120 m) elevation along north flank of Goose Hill and east of Hayes, and smaller patches at similar and lower elevations on both sides of Lewis River valley. Contiguous deposits upvalley, included in the Amboy Drift by Mundorff (1984), were interpreted as outwash related to a much older drift, informally named the drift of Mason Creek, by Evarts (2004). Weathering-rind thicknesses suggest correlation with Wingate Hill Drift of the Mount Rainier region (Crandell and Miller, 1974; Colman and Pierce, 1981), estimated to be 300-600 ka (Colman and Pierce, 1981; Dethier, 1988), or with pre-Wingate Hill(?) till described by (Crandell, 1987) from locality in Battle Ground quadrangle southeast of map area (Howard, 2002)

Older outwash deposits (Pleistocene)—Unconsolidated, moderately weathered, moderately sorted to well-sorted cobble gravel that unconformably overlies Troutdale Formation (Ttf) approximately 4 km north of Woodland; about 40 m thick. Clast composition indicates a Lewis River rather than Columbia River provenance. Similar to drift of Mason Creek outwash deposits (Qmo), but extends to higher elevation (near 600 ft [180 m] in Deer Island quadrangle; Evarts, 2002), hence interpreted as early Pleistocene glaciofluvial deposits older than drift of Ma-

BASIN-FILL DEPOSITS

Conglomerate (Pleistocene or Pliocene)—Unconsolidated to semi-consolidated, thick-bedded, pebbly to cobbly conglomerate with thin lenses (<2 m thick) of basaltic and quartzofeldspathic sand; poorly to moderately well sorted, clast-supported, commonly imbricated and crossbedded. Less intensely weathered than conglomerate of the Troutdale Formation (Ttf). Clast population dominated by volcanic rocks eroded from Columbia River Basalt Group and western Cascade Range. Found only along the southern boundary of this quadrangle, where conglomerate underlies a dissected bench below 300 ft (100 m) elevation, but is widespread in Ridgefield quadrangle to the south (R.C. Evarts, unpub. mapping). Equivalent to alluvial-fan member of Troutdale Formation of Howard (2002). Age uncertain; probably predominantly Pliocene but may extend into early Pleistocene

Troutdale Formation (Pliocene and (or) Miocene)—Semiconsolidated, massive to crudely stratified, pebbly and cobbly conglomerate with sparse lenses of friable sandstone; moderately sorted to well-sorted and clast-supported, with openwork fabric or sandstone matrix. Underlies broad, south- to southwest-sloping surface south of Lewis River, the Troutdale bench of Mundorff (1964). Scattered patches of similar conglomerate are found north of Lewis River at elevations between 300 and 900 ft (90 and 275 m). Clasts well rounded; clast population dominated by cobbles of basalt from the Columbia River Basalt Group but typically includes light-colored granitic and quartzofeldspathic metamorphic rocks and distinctive, white to light-gray, iron-oxide stained quartzite; clasts of volcanic rocks eroded from Cascade Range are scarce. Sandstone interbeds and matrix of conglomerate range from basaltic grit to micaceous arkose compositionally similar to sandy beds of Sandy River Mudstone (Tsr). These rock types indicate dominant source areas east of the Cascade Range and deposition by the ancestral Columbia River. About 3 km north of Woodland, unit contains a mixed clast population of Columbia River Basalt Group and Tertiary volcanic rocks from the Cascade Range. Sedimentary structures are consistent with deposition during floods in a gravel-dominated braided river system. In most places, upper several meters weathered to reddish-brown clayey soil; in such areas, presence of scattered quartzite pebbles in soil is only indicator of conglomeratic parent material. Wells south of Lewis River penetrate as much as 70 m of conglomerate and show that weathering may extend to depths exceeding 30 m (Mundorff, 1964; Swanson and others, 1993). Basal contact with Sandy River Mudstone is low-relief disconformity. Equivalent to upper member of Troutdale Formation of Mundorff (1964) and to volcanic-clast and quartzite-clast members of Troutdale Formation of Howard (2002). Age

Sandy River Mudstone (Miocene)—Semiconsolidated, wellbedded sandstone, siltstone, claystone, and minor quartzite-bearing pebble conglomerate, pumice-lapilli tuff, and

(Tolan and Beeson, 1984)

inferred from stratigraphic relations outside of quadrangle

lignite. Poorly exposed beneath Troutdale Formation (Ttf)

on slopes of creek valleys incised into Troutdale bench in southeast quadrant of quadrangle, in roadcuts on south side of Lewis River valley, and in quarries along Columbia River valley wall southeast of Woodland; similar, subhorizontally bedded sedimentary rocks sporadically exposed in banks of Lewis River at and upriver from mouth of Houghton Creek tentatively assigned to this unit. Water-well logs indicate this unit is more than 175 m thick in vicinity of Pine Grove. Sandy and silty beds are commonly bluish gray in fresh exposures, rapidly weather to light brown; commonly limonite cemented; consist of subangular grains of quartz, feldspar, various rock fragments, muscovite and minor biotite, tourmaline, magnetite, hornblende. Thin claystone beds varicolored, commonly carbonaceous, tuffaceous in part. Planar and trough crossbeds and cut-and-fill structures that are common in sandy horizons indicate a fluvial depositional environment. Equivalent to lower member of Troutdale Formation of Mundorff (1964) and fine-grained member of Troutdale Formation of Howard (2002). Age is poorly constrained. Plant fossils from near top of unit at localities outside of quadrangle are assigned late Miocene or Pliocene ages (Trimble, 1963; Mundorff, 1964; Tolan and Beeson, 1984), and unit is generally considered to postdate Columbia River Basalt Group (Trimble, 1963; Swanson and others, 1993). In quarries southeast of Woodland, however, flows of the Grande Ronde Basalt overlie, are banked against, or invade this unit, so base must be as old as late

Columbia River Basalt Group

Grande Ronde Basalt (Miocene)—Flows of light- to dark-

early Miocene

gray tholeiitic basaltic andesite; vesicular to microvesicular and aphyric to microphyric to very sparsely plagioclase-phyric, with relatively low-TiO₂ contents (table 1), characteristic of the Grande Ronde Basalt of the Columbia River Basalt Group (Mangan and others, 1986; Beeson and others, 1989; Reidel and others, 1989). Found as erosional remnants banked against Paleogene bedrock and Miocene Sandy River Mudstone (Tsr) on valley wall southeast of Woodland; unconformably overlain by Troutdale Formation (Ttf). Some flows exhibit well-developed colonnade and entablature jointing patterns (best visible in quarry-wall exposures). Typical samples are intergranular to intersertal, with lathlike plagioclase, granular to prismatic augite, and Fe-Ti oxide crystals in abundant dark glass; some flows contain rare pigeonite, olivine or orthopyroxene microphenocrysts. Textures resemble those described by Long and Wood (1986) for correlative flows on the Columbia Plateau. Basalt was erupted from vents in eastern and southeastern parts of plateau and entered northwestern Oregon and southwestern Washington through a wide gap in the Miocene Cascade Range (Tolan and others, 1989; Reidel and others, 1989; Wells and others, 1989). K-Ar and ⁴⁰Ar/³⁹Ar age determinations on Columbia Plateau indicate that Grande Ronde Basalt flows were emplaced 16.5 to 15.6 Ma (Reidel and others, 1989). Based on lithologic, chemical and paleomagnetic properties, most Grande Ronde Basalt flows in this quadrangle can be assigned to informal members corresponding to those defined by Reidel and others (1989) on Columbia

Member of Sentinel Bluffs—One or more flows characterized by blocky to columnar jointing, relatively high MgO contents (4.3 to 4.7 wt percent) and normal magnetic polarity. Some flows contain scarce plagioclase phenocrysts as large as 5 mm long in fine- to medium-grained, intersertal to intergranular, aphyric to microphyric groundmass with minor olivine; commonly diktytaxitic. Chemistry, petrography, and remanent magnetization (J.T. Hagstrum, written commun., 1999) indicate equivalence with Sentinel Bluffs unit of Reidel and others (1989; Beeson and others, 1989; Wells and others, 1989), which is within the N₂ magnetostratigraphic unit of Swanson and others (1979), and was erupted about 15.6 Ma

Plateau (terminology follows that of Reidel, 1998)

Member of Winter Water—Erosional remnant of aphyric to very sparsely plagioclase-phyric, intersertal to intergranular basalt flow with relatively low MgO content (about 3.7 wt percent) and normal magnetic polarity. Crops out downhill from Sentinel Bluffs flow about 1 km southeast of Woodland. At least 25 m thick; consists of thick entablature above thin colonnade. Grades into pillow lava near steep contact with Sandy River Mudstone (Tsr); lava tongues locally invade the sedimentary rocks. Chemistry and remanent magnetization (J.T. Hagstrum, written commun., 1999) indicate flow belongs to Winter Water unit of Reidel and others (1989; Beeson and others, 1989; Wells and others, 1989), which is within the N₂ magnetostratigraphic unit of Swanson and others (1979)

Member of Grouse Creek (?)—Flows of hackly fractured, sparsely microphyric basalt with relatively low to intermediate MgO contents (3.96 to 4.16 wt percent) and reversed magnetic polarity (J.T. Hagstrum, written commun., 1999, 2001). Three flows or flow lobes separated by thin (≤ 1 m) weathered vesicular zones are exposed in large quarry about 2.5 km southeast of Woodland; overlies and locally invades fine-grained sedimentary rocks (Tsr) in quarry floor and basaltic hyaloclastite (Tbh) in adjacent creek. Tentatively assigned to member of Grouse Creek based on chemical similarity to a flow at that stratigraphic position in the western Columbia Basin (S.P. Reidel, written commun., 2004)

Basaltic hyaloclastite—Yellow to brown palagonitic conglomerate, grit, and sandstone; massive to crudely thickbedded, moderately to poorly sorted. As much as 25 m thick. Well indurated where fresh, but typically pervasively weathered and crumbly; prone to slumping. Clast-supported conglomerate composed of well rounded to subrounded pebbles and cobbles of variably vesicular aphyric basalt in matrix of coarse vitric basaltic sand; sandy beds are similar to conglomerate matrix and commonly contain dispersed basalt pebbles. Some angular basalt clasts possess glassy rinds and resemble pillow fragments. Unit locally contains angular clasts of claystone as large as 1 m across, presumably derived from underlying Sandy River Mudstone (Tsr). Chemical analysis of relatively fresh sandstone demonstrates affinity with Grande Ronde Ba-

BEDROCK Intrusive rocks

Diorite (Oligocene?)—Small intrusive bodies of medium- to dark-gray, fine- to medium-grained, seriate to hypidiomorphic granular pyroxene diorite. Composed chiefly of blocky plagioclase (1 to 2 mm long), equant augite (0.5 to 1 mm across), equant to prismatic hypersthene (0.5 to 1 mm across), and equant to irregular Fe-Ti oxide (<0.5 mm across); also minor interstitial quartz and (or) chloritic clay minerals, and local traces of anhedral K-feldspar and biotite: amygdules or miarolitic cavities locally common. Primary igneous minerals partially altered to albite,

quadrangle

brown-tinged augite crystals

mass of feldspar, pyroxene, Fe-Ti oxide, and quartz

Volcanic and sedimentary rocks

dark-gray, aphyric to porphyritic pyroxene andesite. Locally includes minor interbedded volcaniclastic rocks and small unmapped flows of basaltic andesite and dacite. Dominates Paleogene bedrock south of Lewis River; scattered flows also found in stratigraphically lower section north of river. Andesites contain phenocrysts of plagioclase (1-20 percent; 1 to 4 mm long), augite (0-5 percent; <0.5 to 2 mm across), hypersthene (0-3 percent; <0.5 to 2 mm long), Fe-Ti oxide (<0.5 percent; <0.5 mm across), and rarely olivine (<1 percent; as large as 1 mm across; invariably replaced by brown smectite) in an intergranular, intersertal, pilotaxitic, hyalopilitic or cryptocrystalline groundmass; some sparsely porphyritic andesites lack augite or hypersthene or both. Alteration is similar in mineralogy and intensity to that described for basaltic andesite (Tba)

Dacite (Eocene)—Domes, flows, and flow breccia of flowbanded, platy, locally vesicular, generally sparsely porphyritic pyroxene dacite. Typically devitrified or altered; pale reddish-, purplish-, brownish-, or yellowish-gray to dark-gray; black where still glassy. Individual flows may be more than 30 m thick. Contains phenocrysts of plagioclase (≤10 percent; 0.5 to 1 mm long, rarely to 4mm), augite (≤ 1 percent; 0.5 to 1 mm), and (or) hypersthene (≤ 1 percent; 0.5 to 1 mm) and microphenocrysts of Fe-Ti oxide (<0.5 percent) in a pilotaxitic, hyalopilitic, cryptocrystalline, or snowflake-textured groundmass; one flow east of Woodland contains sparse olivine partly altered to dark-green clay mineral. Characteristically exhibits minor to pervasive low-temperature alteration to fine-grained quartz, calcite, hematite, montmorillonite, kaolinite, and

> Tuff (Eocene)—Heterogeneous unit of andesitic to rhyolitic tuff, pumiceous lapilli tuff, and lithic tuff breccia. Very poorly sorted, matrix-supported, relatively coarse-grained deposits predominate; inferred to consist mostly of pyroclastic flow and lahar deposits. Beds typically 3 to 12 m thick; locally in excess of 30 m thick. As mapped, includes sequences of tuffaceous rocks interbedded with and gradational to subordinate pumice-poor epiclastic sedimentary rocks. Generally light-colored, ranging from white to light-gray to light greenish- and yellowishbrown. Carbonized woody debris is present in some lapilli tuff beds, especially near their bases. Phenocrysts rarely constitute more than 10 percent of juvenile material in tuff, and include plagioclase, augite, hypersthene, and Fe-

quartz, chlorite, epidote, smectite, calcite, talc, titanite, pyrite, and hematite. Intrusions in Houghton Creek area

Intrusive basalt (Oligocene or Eocene)—Sill-like body of dark-gray, seriate basalt intruding volcaniclastic rocks in upper Robinson Creek. Consists of phenocrysts and glomerocrysts of plagioclase (as long as 2 mm; containing abundant inclusions of altered glass) and olivine (as large as 1 mm across; completely replaced by brown smectite \pm calcite) in a subophitic groundmass with augite oikocrysts (=0.5 mm), Fe-Ti oxide, and devitrified interstitial glass; abundant smectite replaces glass and fills vesicles and interstitial voids

form western margin of swarm centered in adjacent Ariel Intrusive basaltic andesite (Oligocene? and Eocene)—Dikes

and sills of sparsely to abundantly porphyritic basaltic andesite petrographically similar to basaltic andesite flows (Tba). Largely restricted to a belt north of the Lewis River that trends approximately N. 75° E.; individual dikes generally strike parallel to trend of belt. Two-kilometer-long dike northwest of Schumaker Mountain consists of distinctive, coarsely and densely porphyritic, intersertal, hypersthene basaltic andesite with phenocrysts of plagioclase (40 percent; as long as 8 mm), hypersthene (8 percent; as long as 4 mm), and sparse augite (<0.5 percent; as large as 2 mm across) in a groundmass of red glass (partly replaced by smectite) containing skeletal Fe-Ti oxide and

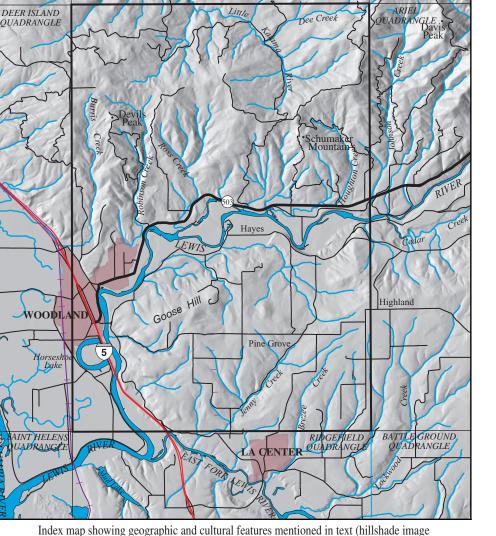
Intrusive andesite (Oligocene? and Eocene)—Dikes and small elongate intrusions of aphyric to porphyritic pyroxene andesite and lesser microquartz diorite; most abundant in Robinson Creek area. Lithologically similar to andesite flows (Ta) but typically more altered. Most intrusions are light greenish- to yellowish-gray, moderately porphyritic, and hydrothermally altered; primary feldspar and pyroxene replaced by calcite, chlorite, smectite, kaolinite, zeolite, quartz, and pyrite. Plug-like cylindrical intrusion in Robinson Creek composed of sparse plagioclase (0.5 percent; 0.5 to 1 mm long) and augite (0.1 percent; 0.5 to 1.5 mm across) phenocrysts in a strongly flowbanded, locally microvesicular, cryptocrystalline ground-

Basaltic andesite (Eocene)—Flows and flow breccia of dark gray to brown, porphyritic to seriate to (rarely) aphyric basaltic andesite and basalt; unit locally includes minor andesite flows and volcaniclastic rocks too small or poorly exposed to map. Typical flows contain phenocrysts of plagioclase (10-35 percent; 1 to 2 mm, rarely to 5 mm long), olivine (as much as 6 percent; 0.5 to 2 mm across; commonly partly resorbed and surrounded by rinds of granular pyroxene and (or) magnetite; almost invariably replaced by some combination of smectite, hematite, carbonate, serpentine, and quartz; commonly contains minute chromian spinel inclusions), and augite (as much as 6 percent; 0.5 to 3 mm across). Some flows lack olivine and (or) augite phenocrysts; many contain microphenocrysts of Fe-Ti oxide and a few contain phenocrysts of hypersthene (as much as 3 percent; 0.5 to 1 mm long). Intergranular to trachytic groundmass consists of the same miner als plus minor interstitial glass (mostly altered to smectitic clay, quartz, or calcite)

Andesite (Eocene)—Flows and flow breccia of medium- to

Volcaniclastic sedimentary rocks (Eocene)—Diverse assemblage of continental volcaniclastic rocks of inferred epiclastic origin. Consists of generally well bedded, wellsorted to poorly sorted siltstone, sandstone, conglomerate, and breccia, all composed chiefly of volcanic debris. Locally includes thin beds of pumiceous pyroclastic rocks and lava flows too small or poorly exposed to map. Beds most commonly light green to olive green or greenish gray but also white, tan, brown, or maroon. Texturally and compositionally immature; most abundant clasts are volcanic rocks petrographically similar to interbedded lava flows and tuffs; other components include plagioclase, Fe-Ti oxide, and pyroxene crystals, pumice, vitric ash, fragments of fine-grained dioritic rocks, and carbonized plant remains. Interpreted as debris eroded from older and penecontemporaneous volcanoes and deposited by normal fluvial and lacustrine processes in low-lying medial to distal intervolcano environments. Unit typically displays intense low-grade alteration to clay minerals and zeolites

Ti oxide, but no quartz, hornblende or biotite. Original



derived from 10-m DEM of the Woodland 7.5' quadrangle and vicinity)

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